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## **Converter Topologies for Switched Reluctance Motors for Electric Vehicle Application**

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**ABSTRACT**: Switched Reluctance Motor (SRM) due to its advanced application is the best suited candidate for the propulsion system of the electric vehicles (EV) and hybrid electric vehicles (HEV). It can be used in any severe operating condition, as it is compact in design and is able to produce required torque and speed. There are several types of converters used for SRM drives. In this paper, two converters are analyzed for SRM based Plug-in HEV. The reduced switch (RS) converter has four current controlling modes that are able to produce additional 2 voltage levels. The high demagnetizing voltage developed by the converter can be used to decrease the demagnetization period which can minimize the torque ripples. The results of this converter are compared with commonly used C-dump converter using MATLAB/SIMULINK.

KEYWORDS: Switched Reluctance Motor, Electrical Vehicle, C-dump converter, Reduced Switch Converter.

#### I. INTRODUCTION

In recent years, growing concern about the environmental protection and depletion of fossil fuels forced the automobile industry to look for alternative resources. Hence, the plug-in hybrid electric vehicles have come into attention as a future of automobile industry [1]. Due to the rapid increasing demand for the drives having variable speed characteristics and the advancement in power electronic semiconductors, SRM (Switched Reluctance Motor) drives have gained extensive use in electric vehicle applications in recent years [1-2]. Recent advances in power electronic technology have made the switched reluctance motor an attractive choice for many industrial as well as automobile applications. Switched reluctance motors are compact in nature. Ruggedness and simple construction are the main advantage of SRM over other machines. Also, this motor doesn't have a rotor winding and it doesn't need a magnetized rotor for operation. It has a pivotal drawback of more ripples in torque output due to discontinuity in the output torque [3-5]. The reason for torque ripples in the output of motor is that at the time of commutation of current of each phase, the reference current leads the stator current due to the back EMF [6]. This causes the phase current reduce to zero after the reference current during the commutation, resulting into production of negative torque and increased torque ripples are introduced at the output of the motor [7]. Thus, it becomes necessary for the SRM drive to use the converter having the fast current commutation capability, resulting into considerable reduction in torque ripples [2].

Currently, there are various types of converters. Each type of converter has its own characteristics, especially Cdump converter. By using this converter, control technique will be easier and negative torque produced by the motor switched reluctance can be reduced. To reduce negative torque, converter will demagnetize the winding faster during the phase change process [8-9]. This paper presents an energy efficient c-dump converter topology, the biggest disadvantage of using this type of converter is higher torque ripple. As it is a two-level converter, the control over the tail current of each phase is compromised which is the main reason behind the production of torque ripple [10-12]. Thus, a second converter with reduced switches is compared with the c-dump converter in this paper.

#### **II. SWITCHED RELUCTANCE MOTOR CONTROL**

Switched reluctance motor has the advantages found in the motor such as a simpler structure and low cost compared to Brushless DC because there are no permanent magnets embedded in the rotor. Switched reluctance motor is able to operate at variable temperatures. The working principle of this motor is based on the difference of magnetic reluctance where the motor will receive a source voltage and producing a magnetic field in the stator winding and pulling the position of the nearest rotor and generating motor rotation. The number of rotor and stator in the motor is quite variant depending on the application. For the operation of switched reluctance motor, it needs to be switched continuously. Therefore, this motor got popularity after the introduction of power electronic devices which can be used for switching the phases of SRM. SRM have variable reluctance between the rotor and stator



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which suggests the name "Reluctance Motor" [4]. Figure. 1 shows the basic block diagram of SRM drive. It consists of input supply to the drive the converter, a controller and an SRM motor. The controller takes the feedback from the motor to control the drive.



Fig.1. Block Diagram of SRM based Electric Vehicle Control

Figure 2 shows the speed-torque characteristics of switched reluctance motor drive. Generally, it is divided into three parts namely constant torque, constant power and natural mode region. Constant torque region is also known as low-speed region. The torque equation for the SRM can be given as

$$T_{ph}(\theta, i) = \frac{1}{2} i_{ph}^2 \frac{dL_{ph}(\theta)}{d\theta}$$
(1)

where,

 $T_{ph}$  – Torque per phase

 $i_{ph}$  – phase current

 $\theta$  – Rotor position angle

For the production of effective torque, the current of the phase winding must be in phase with the position of rotor. For positive torque (i.e. motoring torque), the phase current must be switched with respect to the rotor movement from the unaligned towards the aligned position. The torque equation (1) shows that for motoring torque, the phase current must be synchronized with the rising inductance region. This SRM drive characteristics are best suited for the driving vehicle load. In constant power region as speed of motor increases, torque decreases. Then motor runs continue in natural mode [1-2].



Fig.2. Speed Torque characteristics of SRM drive



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#### **III. CONVERTER TOPOLOGIES**

Figure 3, shows a circuit of energy efficient C-dump converters. The source voltage is separated from the demagnetization pathway. The converter will receive energy from the turns of each phase and flow directly into the capacitor. In this circuit, there is an inductor to limit the current during the use of the capacitor to the DC source voltage. The capacitor is used to store energy when the switch is turned off as prescribed [13-15].

When chopping mode, the converter will experience freewheeling mode past the switch Sd. Switching Sd will continue on if there is no specified command. When Sd is OFF, the energy will flow to the capacitor until the voltage of the capacitor reaches the reference value then the Sd is ON. In order to keep the current ripple from not too high a value, the switching frequency must be increased. During the change in the voltage phase, the capacitor will continue to be maintained at the VDC level. The change in voltage contained in the capacitor is inversely proportional to the value of the previous capacitor value. The energy source from the per phase winding is fed to the capacitor dump before reaching an equal position. The voltage value of the capacitor dump is maintained twice the source voltage to produce a faster demagnetization process. The energy stored in the dump capacitor will be transferred to the source using the chopper operation as a buck converter. There are four switches that function as controls in several converter operating modes.



Fig.3. C-dump converter circuit

The reduced switch converter is shown in Fig. 4. An extra capacitor  $C_2$  is provided which has a boosting capacity. An additional semiconductor power switch (IGBT)  $Q_B$  is also provided for the control of boost voltage. The main function of this boost capacitor  $C_2$  is to charge the demagnetization current which can be free-wheeled through diode  $D_1$  and  $D_2$ . The control over the boost voltage is possible with the switching of the power switches for keeping it constant. The modes of operation for the converter are the excitation mode and the wheeling mode denoted. These two modes are also same for the conventional asymmetric converter. The two common voltage levels can be supplied to the phase winding by these modes (i.e.,  $V_{dc}$  and zero voltage). In the boost wheeling mode, the main function of capacitor is to free-wheel the phase current through it. During this mode, the phase voltage become  $-V_{cd}$ . In demagnetization mode, the energy stored in each phase winding can be returned back to the capacitor  $C_2$ . The average value of voltage for each phase obtained in this mode is  $-(V_{dc} + V_{cd})$ . This is the higher negative voltage as the winding current is returning through the capacitor  $C_2$ . The extended tail current responsible for the torque ripple can be reduced to zero quickly with the help of this higher negative potential in the high-speed region.



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Fig.4. Reduced Switch converter circuit



The two converter circuits are modelled and simulated for a SRM based EV drive using MATLAB/SIMULINK. The current, torque and speed of the C-dump converter SRM drive is shown in Fig. 5,6,7 respectively. The current, torque and speed of the Reduced count converter is shown in Fig. 8,9,10 respectively.



Fig. 5. Phase A Current of C-dump Converter SRM drive

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Fig. 8. Phase A Current of C-dump Converter SRM drive

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Fig. 10. Motor Speed of C-dump Converter SRM drive

#### V. CONCLUSION

The energy efficient of C-dump converter with inductors make one of the converters used to drive Switched Reluctance Motor. With control techniques using several predetermined reference values, there are two reference values as a comparison. The higher the voltage values on the capacitor, the higher the speed produced by switched reluctance motor. This converter can reduce the negative torque by accelerating the changing process of switching each phase. Also, for the high speed SRM drive, the reduced switch configuration converter makes it capable to provide higher negative voltage across the phase for phase winding demagnetization. The demagnetization time of each phase can be reduced with the help of this higher negative voltage (demagnetization voltage) which reduces the tail current. As the tail current is reaching zero quickly, the ripple contents of torque can be minimized and smooth torque can be produced as compared to 2-level converters.

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